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Putting the Puzzle Together: Scientists' Metaphors for Scientific Inquiry

This study describes specific metaphors commonly used by scientists to articulate aspects of their conception of scientific inquiry.

Metaphors are used as a typical way to negotiate and to describe our everyday experience. In the classroom, teachers commonly employ metaphors to engage students and to make abstract ideas appear more concrete (Ogborn & Martins, 1996; Thagard, 1992). In particular, metaphors provide an effective means to help visualize abstract ideas (Davidson, 1976; Miller, 1979). We feel that understanding the metaphors scientists use will assist teachers in crafting classroom discourse that will guide students' developing understanding of scientific inquiry. Lemke (2003) argues that the languages of science are complex and that teachers rarely teach about how to converse in ways that are like scientists. Our study describes and characterizes metaphors used by academic research scientists as they described their experiences with authentic scientific inquiry.

Theoretical Framework

Lakoff and Johnson (1980) articulated metaphors as based in a shared experience and containing links between the form of the metaphor and the real idea that the metaphor seeks to describe. Pugh, *et al*. (1992) extend Lakoff and Johnson's model and describe *grounding* as the need for a metaphor to be based in a shared experience. *Form* refers to the commonality of imagery between the two concepts that is essential if a metaphor is to be successful. For example, in comparing the structure of the atom to the solar system, the form is an image of objects orbiting around a center. *Correspondences* are the multiple points of comparison between the two concepts within the form. The more correspondences there are, the more complete and potentially persuasive is the metaphor. Finally, *connotation* addresses the extent to which a metaphor defines a particular experience. That is, how much has the metaphor entered the culture?

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Methodology

Interviews with 52 science faculty members at a large midwestern academic research institution were conducted using a semi-structured interview protocol designed to probe the subject's conceptions of scientific inquiry (Harwood, Reiff, & Phillipson, 2002). Interviews were tape-recorded and interviewers took field notes during the interview. Together, the transcripts and field notes represent our data. The scientists interviewed were disbursed across nine science departments (anthropology, biology, chemistry, geography, geology, medical sciences, physics, applied health, and environmental affairs) and a wide variety of specific research fields.

After conducting the interviews, we independently analyzed the science faculty members' responses to each of the eight interview questions. Potential metaphors were identified. Following a constant comparison methodology, we compared our independent lists of metaphors and agreed on a consistent understanding regarding how to classify items (Bogdan & Biklen, 2003). The result was a list of metaphors and another list of what we defined as, "every day life examples." These every day experiences were not classified as metaphors. As an example of how inquiry plays a role in a person's every day business, a medical science researcher gave the following response:

> "teaching, interviewing, fixing a car, cooking, business. Let me put it this way, I can't think of many things that scientific inquiry doesn't, one way or the other, play a role in a person's life. They are doing it but they don't know it's scientific inquiry. They just ask the question, search for an answer, and then make improvements next time. That is essentially what is happening in their thinking."

We then independently read through the interviews a second time to double-check for a complete list of metaphors and to collect the metaphors into initial categories. When a discrepancy between our individual categorizations occurred, the results were discussed until a mutual agreement could be made (Tobin, 2000).

Results and Discussion

The scientists' metaphors provided powerful images to complement descriptions of important aspects of scientific inquiry. Scientists used metaphors to describe the process of connecting data, the importance of knowing how and when to use resources or tools, the ability to remain open minded, the relationship between problem solving and scientific inquiry, and the necessity of enhancing scientific knowledge by adding creativity and individuality to an investigation.

Often the metaphor used by a scientist filled multiple purposes and contained a rich set of correspondences. Five key characteristics associated with scientists or with aspects of the processes associated with doing scientific inquiry emerged where the scientists tended to use metaphors. These were: *open-mindedness*, *putting yourself in your work*, *utilizing resources*, *problem solving*, and *making connections*. Below we look at each of these characteristics and describe the metaphors used.

Open-mindedness

An important characteristic of a scientists engaged in a study is the ability to remain open-minded regarding the results of the study. Scientists who are overly concerned with proving a hypothesis may overlook data in the rush to communicate findings to peers. This open-minded realism (Harding & Hare, 2000) encapsulates the investigator's challenging task of being willing to be wrong in their expectations regarding their scientific inquiry.

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Remaining open-minded during the process of scientific inquiry allows the investigator to consider that their expectations or their understanding of other aspects of the study may not be correct. Thus, an investigator can be more open to discoveries or to data that is contradictory to what was expected. A physicist used the metaphor of the SCIENTIST AS ARTIST,

> It's like an artist. An artist does not know the answer. An artist in the process of creating something lets the process lead them to whatever they are doing. They experiment and that's kind of what you do in science.

The correspondence of this metaphor to the experience of being a scientist requires that we understand that authentic scientific investigations do not progress in a linear way where one step invariably leads to the next. Scientists may not know exactly how their investigation will progress and so must be open to the process of scientific inquiry in the same way an artist is open to their muse.

This metaphor reminds us that scientific inquiry is not set of proscribed steps with a known outcome. Rather, it is an exploration into the unknown, but knowable world. A nice description of this type of exploration in a high school setting is given in Crawford's (2000) case study. In one instance (p. 923), the teacher indicates that he doesn't really know what will be discovered as they begin analyzing data from a nearby river. He conveys both his excitement for discovery and his open-mindedness toward the results they may find. In this way, the teacher provides an example for his students of this characteristic of a good scientist.

Putting yourself in your work

Lemke (2003) and others understand that science is not a dispassionate search for objective truth. The image of the emotion-less scientist may encourage non-scientists, including children, in believing that science is boring enterprise devoid of passion. Scientists in our study, however, described doing science as a much more creative endeavor where they design methods and look at data in many different ways. To develop new knowledge about the world entails putting a little of yourself into your work.

A medical scientist compared coming up with something new in science to cooking. In this view of SCIENCE AS COOKING, the scientist does not suggest just following a recipe. To do so will not lead to a new dish or concoction. Adding a spice here and there, however, or substituting items can create a recipe unlike the original. Similarly, scientific progress can result from trying out different variations of an idea. The correspondence of this metaphor with the experience of a research scientist is in feeling that the investigation is their own. An anthropologist compared doing scientific inquiry to PLAYING A CELLO.

> Yo Yo Ma, who is a cello player, says that interpretation is not passive. It's not just playing the notes as they are written; it's putting something of your own, yourself there.

Other metaphors that scientists used that have similar correspondences regarding ownership of the process of scientific inquiry include SCIENCE AS FARMING and SCIENCE AS GARDENING.

> Farmers do that today in determination of when to plant, what to utilize in the fields. They use the available evidence of what they're told and they fit that in with their experience and what their father or their grandfather did

If further studies are needed, the farmer or gardener may repeat appropriate stages of inquiry and redesign the experiment using different controls. The farmer guides the process according to their own goals and purpose much as a scientist guides the process of scientific inquiry to gain a deeper understanding of their questions.

> Let's say somebody is a gardener. Maybe they tried growing tomatoes in different locations or different amounts of sun or the soggy part of the garden as opposed to the dry part of the garden.

Scientific inquiry was also compared to the creative act of WRITING POETRY. The construction and selection of styles of poems is similar to the process of designing and choosing methods to form and shape a study. Writing poetry and designing a study are creative endeavors that involve the self in producing a unique creative work within a structural frame. Interestingly, Watts (2001) has recently argued for explicit connections between science and poetry in school curricula.

Teaching science in ways that do not engage students in the process of inquiry reinforces an image of science and scientists as lacking creativity (Moravcsik, 1981).

Scientific inquiry is not an unemotional, detached, and uninvolved activity where results are known and nothing out of the ordinary ever happens. A scientist from applied health described contrast between teaching that emphasized reciting facts found in a science textbook and the importance of involving yourself in your work.

> That was a big realization for me—you don't actually just learn the book and spit it back; it's like you are making the book.

Utilizing Resources

Scientific inquiry investigations involve the use of resources or tools that will help bring a study to a fruitful resolution of the investigator's question. How a scientist chooses to use the available resources impacts the results of the study. Thus, scientists need to be skilled in selection of the appropriate tool for the investigation and must be able to use the tool in a proficient manner.

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A geographer used the metaphor of teaching someone to fish to explain the importance of knowing how to use the tools in an inquiry investigation. If someone wants to feed him/herself, one does not just give that person the fish. To teach a person how to fish, you give them a rod or the tools necessary to fish then assist them in developing skills and techniques in fishing. This is similar to carrying out scientific inquiry investigations—the investigator must know how to conduct the research and not just be focused on getting the fish or the "right answer."

Several scientists mentioned the role of a metaphorical TOOL BAG in an inquiry investigation. Each tool bag contains methods, instruments, questions, techniques, and it is up to the scientist to decide which tool to use, and when, in an investigation.

> and then I think the other thing that you need is a kind of tool bag and you gotta have a lot of different tools because typically one tool isn't going to get you what you wanted.

Knowing how to make effective use of resources equips scientists to conduct successful investigations. A chemist compared competency with the tools used in inquiry investigations with the skills used in PAINTING. A painter must know how to use the brush, the paints, and the canvass to construct a painting, just as a scientist must be proficient at using available tools to enhance investigations.

The ability to "make connections" between the data was most frequently cited as the most important characteristic of doing scientific inquiry.

Problem-solving

In the course of conducting a scientific inquiry any number of problems may be encountered. Indeed, this experienced reality is often summed up humorously as "Murphy's Law" stating that if anything can go wrong, it will (and usually at the worst possible moment). Solving these unexpected problems can be a major use of investigators energy. The need to address vexing problems in daily life led some scientists to relate problem solving in a scientific inquiry to solving problems in their everyday lives. In these scientists' view, non-scientists can benefit by approaching and solving everyday life problems in the same way scientists approach solving scientific problems.

A common metaphor form for problem solving strategies is one we call "the lawnmower metaphor." The Lawnmower metaphor refers to a set of metaphors that take the form of repairing a complex machine (SCIENCE AS ENGINE REPAIR). The metaphor is used to describe the systematic process that scientists use as part of the problem solving strategy within an inquiry. This metaphor also contains within it the need of scientists to use failure to inform the progress of their inquiry.

> [You] take your lawnmower you pull the cord and it starts. You went in with certain assumptions. You're going to have clean gas, you're going to have a full level of oil. Well, you go one day and you pull the cord and it doesn't work. You begin questioning those things you assumed are in place. You think about it. You check the gas. You check the oil level. You check all these things basically you assumed at the outset when you walked up to the lawnmower. Then you find out where you went wrong. And you hope it's one you know and can control. You hope that it's not some working part that you don't have knowledge of. You really think about what you're doing. At least the way I do. It all comes down to solving problems and understanding whenever you get an unexpected result the first thing you have to do is assume—assuming everything in the experiment was done correctly—assume that you made an erroneous assumption. And you've got to locate that and fix it and retry.

Notice that the process of problem solving described by this scientists moves from simple solutions to more complicated solutions—a commonly identified characteristic of the nature of science.

Making Connections

The ability to "make connections" between the data was most frequently cited as the most important characteristic of doing scientific inquiry (Harwood, Reiff, & Phillipson, 2002). This skill in making connections involves the use of analytical and critical thinking skills to identify patterns and inconsistencies across the data. Scientists recognized the importance of individual pieces of data but also how the data can be connected to provide a pattern, model, or theme.

For example, a geologist used the metaphor of SCIENCE AS A BRICK BUILDING to represent the significance of each piece of data (a brick) in the analysis of the larger set of data corresponding to the overall stucture.

> I think science has a very big building of bricks, not always a capstone. Everybody puts their brick here and there and not all bricks are superior important ones like a capstone or something but every brick counts.

Even data from separate investigations can be connected to enhance an understanding of a scientific concept.

Another part of making connections is to be able to focus on current investigations, but also to have insights into implications of the study and further possibilities for research. A biologist articulated this process with the metaphor of SCIENCE AS A CHESS GAME in that one needs to be able to "recognize the important questions but be able to look ahead 5-6 moves." Connections also need to be made with the existing body of literature on a topic. A chemist used the metaphor of SCIENTIFIC INQUIRY AS LEARNING A FOREIGN LANGUAGE to describe the process of connecting the body of known information to the new information arising from the current study.

> "this ability to think abstractly about a problem is absolutely crucial. It's also crucial to have a lot of facts at your disposal it's very vaguely like learning a foreign language. You have to learn syntax and grammar and that's the thinking abstractly part, how things were generally put together. But, also to learn a foreign language you have to learn vocabulary. In science you must know a set of a reasonably large number of facts."

A scientist needs to be fully aware of details, but not lose sight of how these might fit into the "Big Picture". A geologist used the metaphor of SCIENTIFIC INQUIRY AS BUILDING A MOSAIC ARTWORK in just this way. They point out that in making a mosaic, the artist had to decide how the pieces would be placed and arranged in the picture. The important part is not to loose track of the individual pieces. At first the artist might just have a pile of yellow, purple, and brown mosaic tiles but how these are placed together or connected will determine how the picture will look.

A geographer used the metaphor of being able to see the forest through the trees as an essential characteristic of an investigator in scientific inquiry. Scientists who are so focused on the details of an investigation (the trees) may not be able to take a step back and see how the data are connected (the forest).

Explicit use in the classroom of metaphors that focus on the five characteristics we identified may provide students with a clearer understanding of the nature of science and scientific inquiry.

> Being able to synthesize the big picture but also at the same time concentrate on the details—not losing sight of the forest from the trees, but also looking at the tree itself.

This ability to make connections is an essential characteristic of conducting scientific inquiry investigations. This skill requires the ability to synthesize large amounts of data and to see the patterns that exist between the data so that the meaning can be given.

Conclusion

> 'When it comes to atoms, language can only be used as in poetry. The poet, too, is not so concerned with describing facts as with creating images' (Niels Bohr, quoted in Mashhadi, 1997).

The metaphors used by scientists to articulate aspects of their conception of scientific inquiry identified five broad characteristics of scientists engaged in scientific investigations: *open-mindedness, putting yourself in your work, utilizing resources, problem solving, and making connections*. Specific metaphors such as lawnmower repair, painting, musical performance, cooking, and the tool bag elucidate aspects of the process of scientific inquiry and the characteristics of good science.

These metaphors help us to understand the conceptual approaches and experiences that the community of scientists values. Explicit use in the classroom of metaphors that focus on the five characteristics we identified may provide students with a clearer understanding of the nature of science and scientific inquiry. Teachers of science can choose activities that reinforce these perspectives and develop the skills most valued by active research scientists. The use of metaphors helps to describe scientific inquiry in such a way that relates scientific practices with experiences to which people are familiar. In this way, perhaps, students may begin to perceive themselves as modeling scientific inquiry when doing normal activities such as fixing a car or gathering evidence to make an informed decision.

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